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PHYSICS OF THE INNER HELIOSPHERE 1-10R_O
PLASMA DIAGNOSTICS AND MODELS

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1. INTRODUCTION

The outer corona of the Sun is one of the least explored frontiers in solar physics. There is only limited empirical information on the physical conditions in the coronal regions above 1.5 solar radii. This has resulted in significant gaps in the understanding of the physical processes responsible for solar wind acceleration; coronal heating; transport of mass, momentum and energy; particle acceleration and variations in chemical composition. Under the current grant we are conducting a systematic theoretical investigation of coronal plasma diagnostic techniques, particularly diagnostics applicable above $1.5 R_{\odot}$ where conventional optical instruments have been unable to provide the detailed spectroscopic information required to determine many of the critical plasma parameters. The goals of the study are: (1) to identify spectral features that can be used to provide diagnostic information, (2) to develop a thorough understanding of the physical processes responsible for the formation of the spectral features and the sensitivity of the spectral features to parameters describing the physical conditions in the corona (i.e. electron, proton, and ion temperatures, electron and proton densities, mass-flow velocities, chemical composition, etc.), (3) to explore methods of using various types of measurements for determining the physical conditions in the corona and placing constraints on the physical processes responsible for these physical conditions, (4) to determine the requirements these diagnostics place on instrumentation needed to make the measurements (e.g. sensitivity, wavelength resolution and stray light rejection characteristics) and (5) to develop empirical and theoretical models for the inner heliosphere.

During the current reporting period our efforts were directed primarily toward studies on the physics of solar wind flow in the acceleration region (Section 2) and on impulsive phenomena in the solar corona (Section 3). These stu-

dies, and others that we are planning to undertake, have relevance not only to improving knowledge concerning the physics of the solar wind acceleration region, but also to defining scientific objectives and requirements for instrumentation for the Solar Coronal Diagnostics Mission, Solar and Heliospheric Observatory and Pinhole Occulter Facility.

During the current reporting period four scientific papers were presented at meetings and one was submitted for publication. A summary of papers published, submitted and in press as well as presentations at scientific meetings and colloquia are listed in Section 5.

2. PHYSICS OF SOLAR WIND FLOW IN THE ACCELERATION REGION

An important aspect of our theoretical program has been the study of MHD wave propagation in the corona and the study of solutions for steady-state and time-dependent solar wind equations. The objective is to gain insights concerning the physics of the solar wind acceleration region, plasma heating and plasma acceleration processes there and the formation of shocks. The objective is not only to improve the understanding of the physics of the region where the solar wind is generated, but also to provide guidance in the development of experimental techniques for probing this important region of the solar atmosphere.

An area of continuing interest is the physics of solar wind flow in regions with multiple critical points. Recently Habbal (1985) has shown how a polytropic wind model exhibits properties similar to an isothermal solar wind (Habbal and Rosner 1984) when localized momentum addition and/or rapid area divergence produce multiple critical points in the flow. In particular it is shown how under certain circumstances multiple steady solutions can exist. These multiple steady solutions consist of a continuous solution passing through the innermost critical point and other steady solutions involving a steady shock transition. These multiple solutions have the same flow speed at the base of the

corona, but different asymptotic flow speeds. By following the evolution of the solar wind in time, from a steady state with one critical point to a steady state with three critical points, Habbal shows that a standing shock solution is more likely to develop than a continuous solution when momentum deposition occurs close to the coronal base and the equation of motion admits multiple steady solutions. This result is particularly relevant when momentum deposition occurs as a result of a rapidly diverging coronal hole geometry.

Habbal and Boris (NRL) are currently developing a time-dependent solar wind code to study the effect of thermal conduction on the formation of a standing shock when momentum and/or heat are added to the subsonic solar wind flow. The aim is to determine whether the formation of a standing shock in the inner solar wind is merely a property of isothermal or polytropic winds, or whether it is a more general phenomenon. If the formation of a standing shock is possible, this could have very important consequences on the properties of the solar wind. We are also developing a two-fluid time dependent code to follow the behavior of the electrons and protons independently through the shock.

We also have developed a computer code for determining the effective "temperature" of the corona from empirical electron density distributions using the formulation given by Munro and Jackson (1977, *Astrophys. J.*, 213, 874). The effective temperature is defined as the temperature needed to maintain the pressure balance in the solar wind and includes both thermal and non-thermal pressures (due for example to wave-particle interactions). This code is being applied to existing data for comparison with temperatures determined by other means, for example, from Lyman alpha measurements. We are also using the code to determine the uncertainty in "temperatures" inferred from electron density gradients. These are not true temperatures because of the possible effects

of wave-particle interactions. In addition, as shown by Munro and Jackson, a wide range of solutions are possible because of the uncertainty in the pressure at the upper boundary. However, the effective temperature can provide information on the possible existence of significant non-thermal pressures. A comparison of measured (Lyman alpha) temperatures and inferred effective temperatures for the region observed in the 1980 rocket coronagraph flight suggests that there were no significant nonthermal pressures present in the observed region at the south solar pole.

3. IMPULSIVE PHENOMENA IN THE SOLAR CORONA

One of the objectives of our research program is the development of techniques for placing constraints on the mechanisms responsible for coronal heating. We have undertaken several studies of Skylab EUV observations in order to exploit existing data for this purpose and to gain insights as to what types of observations should be acquired in the future from ground-based instruments, from SMM and from proposed future experiments such as SOT and its co-observing instruments. We discuss below the results of a recently completed study made using Skylab data and preliminary results of new VLA observations acquired in order to determine the desirability of making simultaneous VLA and space (e.g. from SMM) observations in the future.

Skylab EUV observations were used to study the temporal and spatial variations of EUV emission from a small growing active region. Frequent localized short term (~few minutes) fluctuations in EUV emission were observed throughout the 7.2 hour interval when the most continuous observations were acquired. Approximately 20% of the 5" x 5" pixels had intensity variations exceeding a factor of 1.3 for the chromospheric Lyman α line, a factor of 1.5 for lines formed in the chromospheric-coronal transition region and a factor of 1.4 for the coronal Mg X line. A subflare in the region produced the largest in-

tensity enhancements, ranging from a factor of ~ 2.3 for the chromospheric Lyman- α line to ~ 8 for the transition region and coronal lines. The EUV fluctuations in this small active region are similar to those observed in coronal bright points, suggesting that impulsive heating is an important, perhaps dominant form of heating the upper chromospheric and lower coronal plasmas in small magnetic bipolar regions. The responsible mechanism most likely involves the rapid release of magnetic energy, possibly associated with the emergence of magnetic flux from lower levels into the chromosphere and corona. Preliminary results of this work were presented at the June 1984 meeting of the American Astronomical Society. A paper describing results of the detailed analysis of the observations has been submitted to *Solar Physics* ("Impulsive Phenomena in a Small Active Region", by Withbroe, Habbal and Ronan).

As a consequence of our findings that the EUV emission from coronal bright points frequently exhibits short term temporal and spatial variations characteristic of impulsive heating, we acquired VLA observations of coronal bright points in order to determine whether such phenomena could be detected at radio wavelengths. Preliminary results indicate that significant fluctuations in the intensity and degree of polarization are present on temporal scales of a few minutes. Furthermore, the results show an anticorrelation in the variation of the intensity and degree of polarization. At both wavelengths observed, 6 and 20 cm, the brightness temperature of the coronal bright points was in the range 3 to 5×10^9 K. On the basis of these results it appears highly desirable to acquire simultaneous VLA measurements with both SMM and Spacelab 2. We plan to present a paper on the VLA results at the January 1985 meeting of the American Astronomical Society.

The study of the EUV emissions from two active regions continued. As indicated in the last progress report the loops in these two regions exhibit tem-

poral variations on both short (few min) and long (hours) time scales. Preliminary results were presented at the June meeting of the American Astronomical Society (Ronan, Habbal and Withbroe 1984). More detailed analysis is continuing and a paper describing the results is in preparation.

4. FUTURE WORK

In collaboration with E. Leer and R. Esser (Norway) we are planning to undertake a parameter study of the role of Alfvén waves on the solar wind. By developing a two-fluid model of the solar wind with Alfvén waves it will be possible to compare the results with measurements from the Lyman Alpha Coronal Spectrometer and to set limits on the Alfvén wave fluxes likely to be present in the corona. We also plan to continue (1) other theoretical work on time-dependent and steady-state phenomena in the solar wind acceleration region, (2) studying temporal variations in the low corona using existing Skylab and radio observations and (3) investigating the formation of XUV iron lines in the outer corona and their use as plasma diagnostics.

5. PAPERS PRESENTED, SUBMITTED FOR PUBLICATION OR IN PRESS

- Doyle, J. G., Raymond, J. C., Noyes, R. W. and Kingston, A. E. 1984, "The EUV Spectrum of Sunspot Plumes. II. Spectral Diagnostics and Implications for Cooling", submitted to *Astrophys. J.*
- Ferrari, A., Habbal, S. R., Rosner, R. and Tsinganos, K., 1984, "A Wind Type Model for the Generation of Astrophysical Jets", *Astrophys. J.*, **277**, L35.
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- Habbal, S. R. 1984, "The Formation of a Standing Shock in a Polytropic Wind Model within $1 - 1 R_{\odot}$ ", *Bull. Am. Astron. Soc.*, **16**, 533.
- Habbal, S. R. 1984, "Temporal Evolution of the Solar Wind and the Formation of a Standing Shock", talk presented at the Naval Research Laboratory, June, 1984.
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- Habbal, S. R. and Rosner, R. 1984, "Temporal Evolution of the Solar Wind and the Formation of a Standing Shock", *J. Geophys. Res.*, in press.
- Habbal, S. R. and Tsinganos, K. 1982, "Stellar Winds with Multiple Critical Points and Shock Transitions", presented at 160th meeting of American Astronomical Society, Troy, June, *Bull. Amer. Astron. Soc.*, **14**, 608.
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- Owocki, S. and Scudder, J. 1983, "The Effect of a Non-Maxwellian Electron Distribution on Oxygen and Iron Ionization Balance in the Solar Corona", *Astrophys. J.*, 270, 758.
- Noyes, R. W., Raymond, J. C., Doyle, J. G. and Kingston, A. E. 1984, "The EUV Spectrum of Sunspot Plumes. I. Observations", submitted to *Astrophys. J.*.
- Ronan, R., Habbal, S.R. and Withbroe, G. L. 1984, "Spatial and Temporal Variations of Solar Coronal Loops", *Bull. Amer. Astron. Soc.*, 16, 528 (abstract).
- Tsinganos, K., Habbal, S. R. and Rosner, R. 1983, "Formation of Standing Shocks in Stellar Winds and Related Astrophysical Flows", paper presented at Solar Wind V conference, Woodstock, VT, November 1982. In *Solar Wind V*, NASA Conference Publication 2280, ed. M. Neugebauer, p289.
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